acetamide (7.5 g, 130 mmol, mp 82 °C) and the mixture heated at ca. 100 °C for 24 h. After cooling, the mixture is thoroughly triturated with CH_2Cl_2, in which CH_3CONH_2 is not very soluble, and chromatographed on silica gel, using EtOAc as eluant. The first compound eluted proved to be the diacetamido derivative **32**, produced in 25% yield (35 mg) after crystallization. The second product was the bridged *N*-acetylimino compound (**33**),[9] identical with a sample produced from the bridged imino compound and readily hydrolyzed to that compound. The bridged *N*-acetylimino compound was formed in this reaction in approximately 10–15% yield, but was the major product if the ratio of acetamide to dibromo compound were much smaller, e.g., 15:1. Hydrolysis of the diacetamido compound (20 mg) to the diamino derivative (**34**) was effected by 15% HCl at room temperature for 2 h. After neutralization of the acid with $NaHCO_3$, the product was extracted with CH_2Cl_2, and **34** was obtained as a yellowish solid, 10 mg (70%).

***syn*-($CH_3CONHCH_2,CH_3$)B (32)**: yellow needles (*i*-PrOH); mp 135 °C; IR (KBr) 3000 (weak), 2920 (weak), 1740, 1725 cm^{-1}; ^1H NMR ($CDCl_3$) 1.85 (1 H), 1.98 (3 H), 2.20 (3 H), 5.20 (2 H) ppm; UV (CH_3CN) 381 nm (ϵ 6000), 254 (4600), 232 (14400); mass spectrum, *m/e* 306 (M^+).

***syn*-(NH_2CH_2,CH_3)B (34)**: yellow crystals; mp 222 °C; IR (KBr) 3350 (strong), 2920 (weak), 1740 cm^{-1}; ^1H NMR (D_2O) 1.93 (s, 3 H), 3.39 (s, 2 H); UV (dioxane) 384 nm (ϵ 6600), 255 (7400, sh), 235 (15500); fluorescence (H_2O) 470 nm (ϕ_F 0.05); mass spectrum, *m/e* 222 (M^+).

9,10-Dioxa-*syn*-(4-(carbomethoxy)-1-pyridinomethyl,-methyl)bimane Dibromide (24). Methyl isonicotinate, a less active nucelophile, was refluxed with the dibromobimane without added *N,N*-diisopropylethylamine to give *syn*-(4-$CH_3OOCC_5H_4N^+CH_2,CH_3,Br^-$)B: yellow crystals (MeOH); mp 192 °C dec; IR (KBr) 3000, 1740, 1660, 1640, 1605, 1435, 1305, 1290, 1230, 1120 cm^{-1}; ^1H NMR (D_2O) 1.85 (s, 6 H), 4.30 (s, 6 H), 6.50 (s, 4 H), 8.85 (d, 4 H), 9.50 (d, 4 H) ppm; UV (methanol) 465 nm (ϵ 500), 363 (7000), 270 (7100, sh), 229 (27000).

Acknowledgment. Gilda Iny, Yonah (Cohen) Faust, and Marcia Ben-Shoshan are thanked for help with various aspects of this work, Dr. Shlomo Rozen provided the (diethylamino)sulfur trifluoride and gave useful advice on its use in synthesis.

Registry No. **1**, 68654-22-8; **2**, 71418-44-5; **3**, 68654-25-1; **4**, 68654-23-9; **5**, 76421-69-7; **6**, 76421-70-0; **7**, 76421-71-1; **8**, 76421-72-2; **9**, 76421-73-3; **10**, 76421-74-4; **11**, 76421-75-5; **12**, 76421-76-6; **13**, 76421-77-7; **14**, 74235-78-2; **15**, 74235-77-1; **16**, 76421-78-8; **17**, 76421-79-9; **18**, 76421-80-2; **19**, 76421-81-3; **20**, 76421-82-4; **21**, 76421-83-5; **22**, 76421-84-6; **23**, 76421-85-7; **24**, 76421-86-8; **25**, 71418-45-6; **26**, 76421-87-9; **27**, 76421-88-0; **28**, 76421-89-1; **30**, 76421-90-4; **31**, 76421-91-5; **32**, 76421-92-6; **33**, 76421-57-3; **34**, 76421-93-7; **35**, 76421-94-8; **36**, 76421-95-9; **37**, 76421-96-0; **38**, 76421-97-1; **39**, 76421-98-2; **41**, 76421-99-3; **42**, 76422-00-9; **43**, 76422-01-0; **44**, 76422-02-1; sodium methoxide, 124-41-4; potassium acetate, 127-08-2; potassium terephthalate, 3856-02-8; sodium methanethiolate, 5188-07-8; 1-propanethiol, 107-03-9; *N*-methylaniline, 100-61-8; *N*,4-dimethylaniline, 623-08-5; *N*-methyl-4-chloroaniline, 932-96-7; *N*-methyl-3-bromoaniline, 66584-32-5; 1-naphthylamine, 134-32-7; piperidine, 110-89-4; dimethylamine, 124-40-3; methylamine, 74-89-5; trimethylamine, 75-50-3; ammonia, 7664-41-7; acetamide, 60-35-5; methyl isonicotinate, 2459-09-8.

Bimanes. 7. Synthesis and Properties of 4,6-Bridged *syn*-1,5-Diazabicyclo[3.3.0]octa-3,6-diene-2,8-diones (μ-Bridged 9,10-Dioxabimanes)

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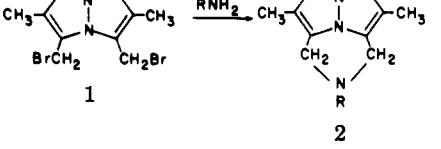
Received October 14, 1980

The reaction of *syn*-4,6-bis(bromomethyl)-1,5-diazabicyclo[3.3.0]octa-3,6-diene-2,8-diones with appropriate difunctional nucleophiles leads to 4,6-bridged *syn*-1,5-diazabicyclo[3.3.0]octa-3,6-diene-2,8-diones (μ-bridged 9,10-dioxabimanes), in which the bridging atoms are carbon, nitrogen, and sulfur. Substituents on the bridging atoms include the following: (a) (on carbon) H, $COOCH_3$, H, COOH, $(COOCH_3)_2$, $(COOC_2H_5)_2$, $(CN)_2$; (b) (on nitrogen) H, OH, $COCH_3$, CH_3, C_2H_5, $(CH_3)_3C$, CH_2CH_2OH, $C(CH_2OH)_3$, $C(CH_2OH)_n(CH_2OCOR)_{3-n}$ (n = 0, 1, 2; R = CH_3, $C_{15}H_{31}$, $C_{11}H_{23}$), $C(CH_2OH)(CH_2OC(CH_3)_2OCH_2$, $(CH_3)_2^+$, C_6H_4X (X = H, CH_3O, CH_3, CN, Br, Cl, $COOC_2H_5$), $(CH_3)(C_6H_4X)^+$ (X = CH_3, Cl); (c) (on sulfur) none, CH_3^+, O_2.

Introduction

In the course of studying the reaction of the *syn*-dibromodioxabimane **1** [*syn*-4,6-bis(bromomethyl)-3,7-dimethyl-1,5-diazabicyclo[3.3.0]octa-3,6-diene-2,8-dione or *syn*-($BrCH_2,CH_3$)B][2] with simple amines, RNH_2, products were isolated that were found to have properties consistent with a "bridged" structure, in which an atom linked the carbons substituted on the 4- and 6-positions of the 1,5-diazabicyclooctane structure (**2**, eq 1).[3]



1 2 (1)

The ring-forming reaction seemed so promising for the preparation of new heterocyclic compounds with interesting photophysical properties and strained rings that a substantial number of derivatives were prepared and ex-

(1) (A) Tel-Aviv University. (b) State University of New York, Stony Brook.

(2) The nomenclature of bimane derivatives is thoroughly discussed in Bimanes 5: Kosower, E. M.; Pazhenchevsky, B. *J. Am. Chem. Soc.* **1980**, *102*, 4983-4993.

(3) Kosower, E. M.; Pazhenchevsky, B.; Dodiuk, H.; Kanety, H.; Faust, D. *J. Org. Chem.*, preceding paper in this issue.

0022-3263/81/1946-1673$01.25/0

amined. The photophysical studies will be described in a separate paper. The X-ray crystallographic studies on one of the bridged compounds has already been communicated.[4] The present paper describes the synthesis and the physical properties of many bridged bimanes.

Results

The reactions of dibromide 1 with primary amines are carried out at room temperature in acetonitrile, with less nucleophilic amines requiring reflux temperatures. Excess amine or added *N,N*-diisopropylethylamine is used to neutralize the hydrogen bromide formed in the reaction, which follows the course indicated in eq 1. The isolation procedure for the product 2 varies with structure but is usually quite straightforward. Exposure to light and air is to be avoided for bridged compounds bearing electron-donor groups.

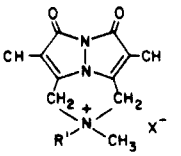
A fair number of different primary amines have been utilized in the reaction with the *syn*-dibromide, including ammonia, methylamine, ethylamine, *tert*-butylamine, 2-aminoethanol, tris(hydroxymethyl)aminomethane, hydroxylamine, benzylamine, 4-methoxybenzylamine, and a series of aromatic amines $XC_6H_4NH_2$, with X = H, 4-CH_3O, 4-CH_3, 4-CN, 4-Br, 4-Cl, 4-$COOC_2H_5$. The bridged products formed in this way are indicated in below.

mu-NR-syn-(-CH_2,CH_3)B

2a, R = H
b, R = CH_3
c, R = CH_2CH_3
d, R = $C(CH_3)_3$
e, R = CH_2CH_2OH
f, R = $C(CH_2OH)_3$
g, R = OH
h, R = $C_6H_5CH_2$
i, R = $CH_3OC_6H_4CH_2$
j, R = C_6H_5
k, R = 4-$CH_3OC_6H_4$
l, R = 4-$CH_3C_6H_4$
m, R = 4-CNC_6H_4
n, R = 4-BrC_6H_4
o, R = 4-ClC_6H_4
p, R = 4-$C_2H_5OOCC_6H_4$
q, R = CH_3CO

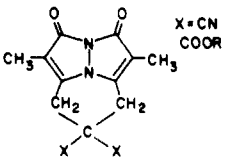
By use of the appropriate ratios of *syn*-dibromide and secondary amines, RNHR′, reaction leads to reasonable yields of bridged quaternary salts **3**. The compounds which have been made are those in which one group is methyl and the second group either methyl or aryl, i.e., R = CH_3 (**3a**), R = 4-ClC_6H_4 (**3b**), R = 4-$CH_3C_6H_4$ (**3c**).

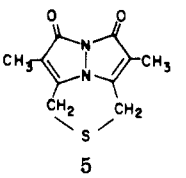
Carbon-bridged derivatives **4** are prepared by the reaction of dialkyl malonates or malononitrile with the *syn*-dibromide (1) in the presence of sodium hydride in tetrahydrofuran. Although the yields of product were not very high, ranging from 22–32%, the reactions were efficient enough to provide material for photophysical studies[5]



3a, R = CH_3
b, R = 4-ClC_6H_4
c, R = 4-$CH_3C_6H_4$

and for a few transformations.





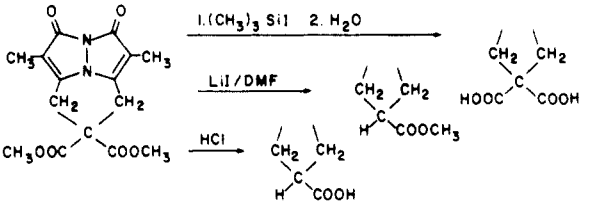
5

4a, X = $CO_2CH_2CH_3$
b, X = CO_2CH_3
c, X = CN

The sulfur-bridged derivative **5** is prepared by the reaction of aqueous sodium sulfide with the *syn*-dibromide or, more effectively, through a two-phase reaction using a phase-transfer catalyst, in 68% yield.

Transformations of Bridged Compounds. Some reactions of the bridged compounds could be carried out with relative ease, whereas others required precisely specified conditions and reagents. Acetylation of the bridged-NH derivative with acetic anhydride leads to the *N*-acetyl derivative (**2a**). Methylation of the bridged NCH_3 compound forms the $(CH_3)_2N^+$ iodide, which had an NMR spectrum identical with that of the perchlorate salt produced via the bromide, the product of the reaction of the *syn*-dibromide and dimethylamine. The sulfur-bridged molecule required the strong methylating agent methyl fluorosulfate for conversion to the *S*-methylsulfonium fluorosulfate salt (**5a**). Oxidation of the S-bridged compound proceeded in a normal fashion, with *m*-chloroperbenzoic acid producing the sulfone-bridged derivative (**5b**).

Three different hydrolysis products could be obtained from the bis(carbomethoxy) carbon-bridged derivative by varying the procedure. Lithium iodide in dimethylformamide led to the monocarboxylic acid monoester (**4d**), whereas trimethylsilyl iodide gave the dicarboxylic acid (**4e**), and heating with 15% HCl produced the monocarboxylic acid (**4f**, eq 2).



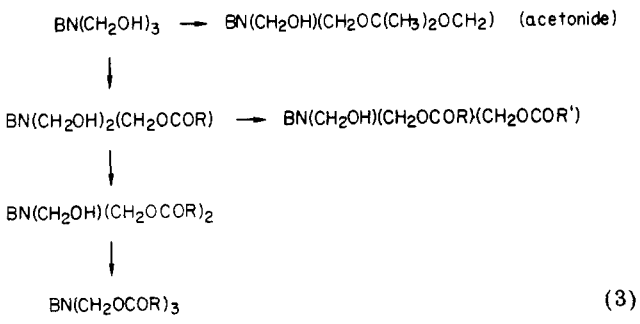
(2)

The tris(hydroxymethyl) nitrogen-bridged molecule could be transformed into a number of potentially interesting acyl derivatives. In addition, an acetonide (**2fA**) which formed particularly beautiful well-faceted crystals (similar to a marquise-cut diamond) was readily produced. Triacyl, diacyl, monoacyl, and mixed diacyl derivatives were produced by acylation with acetic anhydride, palmitoyl chloride, or lauroyl chloride in an appropriate sequence, as shown in eq 3.

Spectroscopic Properties of Bridged Compounds. The longest wavelength ultraviolet absorption band is found at considerably shorter wavelengths than the corresponding band in nonbridged and analogous compounds (360–380 nm in dioxane, and at longer wavelengths in CH_3CN). The positions for nitrogen-bridged derivatives

(4) Kosower, E. M.; Bernstein, J.; Goldberg, I.; Pazhenchevsky, B.; Goldstein, E. *J. Am. Chem. Soc.* **1979**, *101*, 1620. Goldberg, I. *Cryst. Struct. Commun.* **1980**, *9*, 329. Bernstein, J.; Goldstein, E.; Goldberg, I. *Ibid.* **1980**, *9*, 295; *Ibid.* **1980**, *9* 301.

(5) Kosower, E. M.; Kanety, H.; Dodiuk, H., submitted for publication (bimanes 8).



(3)

vary between 327 nm for the *tert*-butylamino-bridged compound to 335 nm for the NH bridge in CH_3CN. Positions for the carbon-bridged compounds are quite similar to those of the nitrogen-bridged compounds, with maxima between 329 nm [bis(carbomethoxy)] and 335 nm (dicarboxylic acid) in dioxane. The band for the sulfur-bridged derivatives is much more sensitive to structure than the others, changing from 333 nm for the SO_2-bridged compound to 345 nm for the S-bridged compound to 356 nm for the *S*-methylsulfonium-bridged derivative, all in CH_3CN.

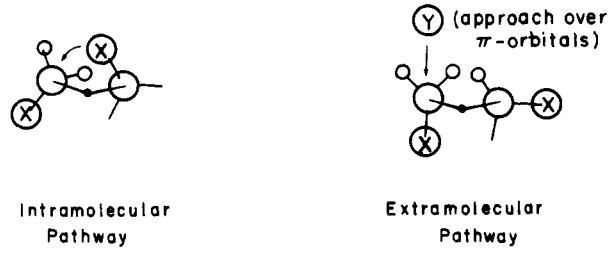
In contrast to the considerable shift to shorter wavelengths for the absorption maxima of bridged compounds compared to nonbridged compounds, the fluorescence maxima are scarcely changed for the compounds described in the present article. (For example, the emission maximum for *syn*-$((CH_3)_2NCH_2,CH_3)B$ in dioxane is at 427 nm and that for the bridged CH_3N compound is at 429 nm in the same solvent.) In nonpolar solvents, the quantum yield of fluorescence from bridged derivatives is usually very high, between 0.6–0.8.

The IR spectra of the bridged 9,10-dioxa-*syn*-bimanes resemble those of the nonbridged compounds. the NMR spectra reveal that the signal for the α-CH_3 group appears at slightly higher field than in the nonbridged compounds and that the signal for the CH_2 group is quite sensitive to the nature of the bridging atom and the nature of the groups attached to that atom. The most important fact about the NMR spectra of all the bridged compounds is that only a single peak is seen for the CH_2 hydrogens of the bridge, the single exception thus far encountered being the *S*-methylsulfonium derivative, for which the spectrum shows a multiplet at 5.0 ppm. In all other cases, a singlet peak is seen, with positions ranging from 3.19 ppm for the bis$(C_2H_5OOC)_2C$-bridged compound to 4.73 ppm for the *N*-acetylamino-bridged derivative.

Discussion

The bond lengths found within a 4,6-bridged 9,10-dioxabimane (the μ-dicyanomethylene derivative) indicate that the molecule is somewhat strained.[4] The facile formation of bridged derivatives through the reaction of appropriate nucleophiles with *syn*-dibromobimanes thus requires some comment. The reaction must be considered in two stages: (1) reaction of the nucleophile with the dibromo compound leading to formation of a monobromo monosubstituted bimane and (2) competition between the neighboring group (i.e., the nucleophile which has already been introduced into the molecule in the first stage) and the external nucleophile present in the reaction solution.

The first stage is subject to steric effects on the part of both the incoming nucleophile and the bimane undergoing substitution. Such effects are not apparent in any of the cases covered by the present paper but are easily seen in kinetic studies on closely related bromobimanes.[6] The second stage is the most important one to examine with respect to the formation of bridged derivatives. We may formulate the two most likely representations of the transition states, shown below, for (a) intramolecular



Intramolecular Pathway Extramolecular Pathway

substitution, leading to bridged compound formation and (b) extramolecular substitution by the nucleophile, leading to a disubstituted product. The bimane is drawn in a somewhat "bent" form, in accordance with our suggestion for the major form in solution.[7] Comparison of the two transition states shows that the energetics and the steric effects expected for each pathway are quite different.

In comparing intramolecular with intermolecular reaction, we must be careful to compare reactions with the same nucleophiles. This type of comparison is particularly difficult to make with the present systems, a point we may illustrate as follows. The SH^- ion must compete with bimanyl-S^- in the reaction which leads either to thia-bridged bimane or to the dithiol of a bimanedithiol. Even though we may expect both groups to have the monoanionic form at neutral pH, the nucleophilicity of the bimanylthiolate ion is probably less than that of the SH^- ion due to the electron-attracting power of the bimane ring. An amino group attached to the bimane will certainly be different from an external amine, and this difference will be reflected in a change in the ratio of intramolecular and intermolecular reaction. Another factor which affects the competition is that of nucleophile size, a factor which operates by affecting the amount of strain in the bridged transition state. The larger the attacking atom, the less strain introduced into the bridged transition state and the more steric strain added to the intermolecular transition state. Sulfur, a large atom, leads to mostly bridged product as the result of the competition between an intramolecular thiolate anion and an external SH^- ion. (The difference in intrinsic reactivity cited above does not decrease the reactivity to a sufficient degree.) Nitrogen, on the other hand, is smaller and should yield more disubstitution product, a idea borne out by experiment. Intramolecular reaction is favored by the high "local concentration" of the nucleophile (10 M is a good approximation for this local concentration). For equal reactivities, the intramolecular nucleophile will always compete successfully against the extramolecular nucleophile. However, strain will diminish the rate of the intramolecular reaction. Certain nucleophiles will be far less reactive when attached after the first stage of the reaction than they are as external nucleophiles. Thus, intramolecular CH_3S is far less nucleophilic than SH^- or RS^-, and CH_3S^- yields disubstitution product along with some reduction product. The kinetic aspects of the substitution reactions are still under study as are certain aspects of bridged-compound formation and we shall report on the results in due course.[6]

New Heterocyclic Systems. The new heterocyclic molecules created by the ring-closure reaction should be open to an interesting variety of other chemical transformations and the synthesis of new heterocyclic systems.

(6) Kosower, E. M.; Radkowski, A., unpublished results.

(7) Kosower, E. M.; Kanety, H.; Dodiuk, H.; Hermolin, J., submitted for publication (Bimanes 9).

Functional groups are easily introduced, as shown by the example of the 2-hydroxyethyl group added through the use of 2-aminoethanol. Heterocyclic molecules with other atoms like phosphorus, selenium, and tellurium could be prepared for the study of the effect of these atoms on the fluorescence of the bimane moiety.

Ring Flexibility. The ^1H NMR spectrum of the bridged bimanes reveals, on the whole, that the bridge hydrogens, when present, are equilibrating with one another. Even when such molecules are cooled to reasonably low temperatures (ca. −90 °C), the NMR spectra are not broadened very much. We must therefore conclude that the bimane ring (the 1,5-diazabicyclo[3.3.0]octadienedione system) must invert very rapidly ($>10^7$ s^{-1} in the ground state at 25 °C). Rapid inversion has been observed for a 1,5-diazabicyclo[3.3.0]octane[8] (ca. 10^2 s^{-1} at −50 °C or $>10^6$ s^{-1} at 25 °C) by NMR and for the corresponding radical cation (ca. 10^8 s^{-1} at −110 °C) by EPR.[9]

Conclusions

New heterocyclic systems in which at least one atom bridges the 4- and 6-methylene groups of the 9,10-dioxa-*syn*-bimane nucleus may be prepared very easily. The new systems provide a promising group of new molecules for further synthetic work. The bridged systems themselves are very interesting from the photophysical point of view and studies on their behavior will be reported in another article.[5]

Experimental Section

Instrumentation used in research on bimanes has been described previously.[2] The Experimental Section is divided into two parts, the first being concerned with the synthesis of the bridged derivatives and the second with some of their simple reactions. The first portion is further divided into sections according to the nature of the atom which forms the bridge, i.e., (a) nitrogen (**2a–p**; quaternary derivatives **3a–c**), (b) carbon (**4a–c**), and (c) sulfur (**5a,b**).

9,10-Dioxa-μ-imino-*syn*-(methylene,methyl)bimane (2a). Ammonium hydroxide (30%, 0.6 mL, 10 mmol) was mixed with *syn*-($BrCH_2,CH_3$)B (1.0 g, 2.86 mmol) in CH_3CN (20 mL) and, after 3 h, the precipitate was filtered off and recrystallized to yield **2a** [μ-(NH)-*syn*-(-CH_2,CH_3)B]: 430 mg (73%); yellow needles (DMF); mp 215–218 °C dec; IR (KBr) 3330, 2940, 1725, 1670, 1640, 1610, 1445, 1415, 1255, 1175, 1070 cm^{-1}; ^1H NMR (Me_2SO-d_6) 1.72 (s, 3 H), 3.81 (s, 2 H) ppm; UV (CH_3CN) 335 nm (ε 5100), 231 (15 000); fluorescence (dioxane) 426 nm (ϕ_F 0.77); mass spectrum (CI), *m/e* 206 $(M + 1)^+$. Anal. Calcd for $C_{10}H_{11}N_3O_2$: C, 58.54; H, 5.37; N, 20.49. Found: C, 58.41; H, 5.32; N, 20.20.

9,10-Dioxa-μ-methylimino-*syn*-(methylene,methyl)bimane (2b). The reaction mixture of *syn*-($BrCH_2,CH_3$)B (1.0 g, 2.86 mmol) with 30% methylamine in ethanol was worked up after 30 min through removal of the solvent, crystallization of the residue from *i*-PrOH, and sublimation at 160 °C (0.01 mm) to yield 300 mg (48%) of μ-(CH_3N)-*syn*-(CH_2,CH_3)B (**2b**): white solid: mp 197–198 °C; IR (KBr) 2950, 1755, 1700, 1660, 1640, 1450, 1390, 1270, 1220, 1175 cm^{-1}; ^1H NMR ($CDCl_3$) 1.82 (s, 6 H), 2.55 (s, 3 H), 3.65 (s, 4 H) ppm; UV (CH_3CN) 331 nm (ε 5700), 252 (sh), 227 (18 500); fluorescence (CH_3CN) 438 nm (ϕ_F 0.64); mass spectrum, *m/e* 219 (M^+). Anal. Calcd for $C_{11}H_{13}N_3O_2$: C, 60.27; H, 5.94; N, 19.18. Found: C, 60.60; H, 6.05; N, 19.33.

9,10-Dioxa-μ-ethylimino-*syn*-(methylene,methyl)bimane (2c). The reaction of aqueous ethylamine (70%, 0.65 g, 10 mmol) with *syn*-($BrCH_2,CH_3$)B (0.50 g, 1.43 mmol) in CH_3CN (10 mL) yielded μ-(CH_3CH_2N)-*syn*-(-CH_2,CH_3)B (**2c**): 220 mg (66%); yellowish crystals (*i*-PrOH): mp 149 °C; IR (KBr) 2930, 1760, 1750, 1675, 1650, 1625, 1445, 1395, 1160 cm^{-1}; ^1H NMR ($CDCl_3$) 1.15 (t, 3 H), 1.83 (s, 6 H), 2.68 (q, 2 H), 3.65 (s, 4 H) ppm; UV (CH_3CN) 334 nm (ε 5100), 253 (sh), 227 (16 500); fluorescence (CH_3CN) 438 nm (ϕ_F 0.52). Anal. Calcd for $C_{12}H_{15}N_3O_2$: C, 61.80; H, 6.44; N, 18.03. Found: C, 61.71; H, 6.53; N, 17.78.

9,10-Dioxa-μ-*tert*-butylimino-*syn*-(methylene,methyl)bimane (2d). The reaction of *tert*-butylamine (0.73 g, 100 mmol) with *syn*-($BrCH_2,CH_3$)B (0.70 g, 2 mmol) in CH_3CN (20 mL) gave a red oil which yielded, after a rough chromatography, μ-((CH_3)$_3$CN)-*syn*-(CH_2,CH_3)B (**2d**): 210 mg (20%); pink crystals (EtOAc–Et_2O); mp 153 °C (turns red on long exposure to air); IR (KBr) 2980, 1755, 1695, 1675, 1660, 1640, 1610, 1425, 1395, 1245, 1205, 1095 cm^{-1}; ^1H NMR ($CDCl_3$) 1.22 (s, 9 H), 1.82 (s, 6 H), 3.71 (s, 4 H) ppm; UV (dioxane) 327 nm (ε 5800), 253 (sh), 236 (11 800); fluorescence (dioxane) 430 nm (ϕ_F 0.58); mass spectrum, *m/e* 261 (M^+).

9,10-Dioxa-μ-(2-hydroxyethyl)imino-*syn*-(methylene,methyl)bimane (2e). 2-Aminoethanol (120 mg, 2 mmol), triethylamine (0.40 g, 4 mmol), and *syn*-($BrCH_2,CH_3$)B (0.70 g, 2 mmol) were reacted in CH_2Cl_2 (10 mL) for 15 h, the solution was washed with water and dried (Na_2SO_4), the solvent was removed, and the residue was chromatographed on neutral alumina (eluant CH_2Cl_2) to yield μ-($HOCH_2CH_2N$)-*syn*-(CH_2,CH_3)B (**2e**): 180 mg (36%); cream-colored crystals (CH_3CN); mp 163 °C; IR (KBr) 3340, 2960, 1760, 1680, 1660, 1630, 1440, 1390, 1160, 1065 cm^{-1}; ^1H NMR ($CDCl_3$) 1.78 (s, 6 H), 1.99 (s, 1 H), 2.69 (s, 2 H), 3.77 (m, 6 H) ppm; UV (CH_3CN) 334 nm (ε 5300), 253 (sh), 228 (16 700); fluorescence (CH_3CN) 439 nm (ϕ_F 0.80). Anal. Calcd for $C_{12}H_{15}N_3O_3$: C, 57.83; H, 6.02; N, 16.87. Found: C, 57.93; H, 5.91; N, 16.67.

9,10-Dioxa-μ-(tris(hydroxymethyl)methyl)imino-*syn*-(methylene,methyl)bimane (2f). Tris(hydroxymethyl)aminomethane (105 mg, 0.87 mmol) and *syn*-($BrCH_2,CH_3$)B (100 mg, 0.28 mmol) were reacted in CH_3CN (25 mL) at reflux for 15 h, the solvent was evaporated, H_2O (10 mL) was added, and the yellow solid was filtered off to give μ-(($HOCH_2$)$_3$CN)-*syn*-(CH_2,CH_3)B (**2f**): 82 mg (95%); yellow solid, scarcely soluble in H_2O, Me_2SO, DMF; dec 228–240 °C (yellow → orange → black); IR (KBr) 3440 (strong, sharp), 3000, 2940, 1740, 1660, 1630, 1440, 1415, 1310, 1240, 1220, 1200, 1190, 1100, 1040, 1020 cm^{-1}; UV (CH_3OH) 335, 232. The compound was too insoluble to obtain an NMR spectrum and gave only fragmentation peaks on attempts to measure the mass spectrum. All derivatives exhibited the expected UV, NMR, and IR spectroscopic behavior, but likewise gave only fragmentation peaks in mass spectra. The properties of the derivatives and their preparation are described in the section on reactions of bridged compounds.

9,10-Dioxa-μ-hydroxyimino-*syn*-(methylene,methyl)bimane (2g). Hydroxylamine hydrochloride (140 mg, 2 mmol), *syn*-($BrCH_2,CH_3$)B (0.70 g, 2 mmol), and *N,N*-diisopropylethylamine (0.78 g, 4 mmol) were mixed in CH_3CN (20 mL). After 20 h, the solvent was removed, and the residue triturated with *i*-PrOH, filtered off, and recrystallized to yield μ-(HON)-*syn*-(-CH_2,CH_3)B (**2g**): 215 mg (48%); yellow crystals (*i*-PrOH–CH_3CN (2:1)); mp 197–198 °C; IR (KBr) 3310, 2920, 1760 (sh), 1740, 1675, 1650, 1625, 1405 cm^{-1}; ^1H NMR (Me_2SO-d_6) 1.71 (s, 3 H), 4.03 (s, 2 H) ppm; UV (CH_3CN) 335 nm; fluorescence (dioxane) 430 nm (ϕ_F 0.65); mass spectrum, *m/e* 221 (M^+).

9,10-Dioxa-μ-benzylimino-*syn*-(methylene,methyl)bimane (2h) [μ-($C_6H_5CH_2N$)-*syn*-(CH_2,CH_3)B]: 50% yield; yellowish crystals (*i*-PrOH), mp 109 °C; IR (KBr) 3040, 3020, 2960, 2920, 2800, 1760 (sh), 1735, 1690, 1660, 1640, 1500, 1450, 1420, 1390, 1355, 1345, 1295, 1270, 1250, 1230, 1200, 1180, 1155, 1090, 1060, 1030, 1010, 990, 970, 910, 890, 860, 790, 770, 760, 730, 700 cm^{-1}; ^1H NMR ($CDCl_3$) 1.78 (s, 6 H), 3.68, 3.70 (d, 6 H), 7.30 (s, 5 H) ppm; UV (dioxane) 331 nm (ε 6000), 226 (17 100); fluorescence (dioxane) 430 nm (ϕ_F 0.73); mass spectrum, *m/e* 295 (M^+).

9,10-Dioxa-μ-(4-methoxybenzyl)imino-*syn*-(methylene,methyl)bimane (2i) [μ-(4-$CH_3OC_6H_4CH_2N$)-*syn*-(CH_2,CH_3)B]: yellowish-white crystals (*i*-PrOH); mp 113 °C; IR (KBr) 3060, 2980, 2960, 2920, 2840, 1745, 1650, 1640, 1610, 1510, 1470, 1370, 1310, 1300, 1255, 1245, 1160, 1140, 1080, 1030, 1010, 970, 950, 890, 860, 825, 810, 790, 770, 760, 730, 710 cm^{-1}; ^1H NMR ($CDCl_3$) 1.78 (s, 6 H), 3.70, 3.85 (m, 9 H), 7.20 (q, 4 H) ppm; UV (dioxane) 330 nm (ε 5700), 227 (25 300); fluorescence (dioxane) 430 nm (ϕ_F 0.73); mass spectrum, *m/e* 325 (M^+).

9,10-Dioxa-μ-arylimino-*syn*-(methylene,methyl)bimanes (2j–p). Anilines (1 equiv plus 1 equiv of *N,N*-diisopropyl-

(8) Kintzinger, J. P.; Lehn, J. M.; Wagner, J. *Chem. Commun.* **1967**, 206–207.

(9) Nelsen, S. F.; Weisman, G. R.; Hintz, P. J.; Olp, D.; Fahey, M. R. *J. Am. Chem. Soc.* **1974**, *96*, 2916.

ethylamine or triethylamine or 2 equiv) were reacted with *syn*-($BrCH_2,CH_3$)B (1 equiv) in CH_3CN (20–25 mL/mmol) for 15 h, usually at reflux temperatures, the solvent was removed, and the residue was purified by chromatography, recrystallization, or sublimation. The properties of each product are described below.

9,10-Dioxa-μ-phenylimino-*syn*-(methylene,methyl)bimane (2j) [μ-(C_6H_5N)-*syn*-(CH_2,CH_3)B]: 83% yield; yellow crystals by sublimation [160 °C (0.005 mm)]: mp 174–175 °C; IR (KBr) 1770, 1755, 1695, 1670, 1640, 1615, 1595, 1495, 1430, 1235, 1175 cm^{-1}; ^1H NMR ($CDCl_3$) 1.85 (s, 6 H), 4.30 (s, 4 H), 6.8–7.5 (m, 5 H) ppm; UV (CH_3CN) 331 nm (ε 5700), 287 (sh), 240 (25 200); fluorescence (dioxane) 429 nm (ϕ_F 0.77). Anal. Calcd for $C_{16}H_{15}N_3O_2$: C, 68.33; H, 5.34; N, 14.95. Found: C, 68.51; H, 5.29; N, 15.14.

9,10-Dioxa-μ-(4-methylphenyl)imino-*syn*-(methylene,-methyl)bimane (2l) [μ-(4-$CH_3C_6H_4N$)-*syn*-(CH_2,CH_3)B]: 38% yield; yellow crystals (*i*-PrOH); mp 213–215 °C (turns red, then brown in air); IR (KBr) 2920, 1745, 1670, 1640, 1515, 1450, 1385, 1360, 1235, 1210, 1010 cm^{-1}; ^1H NMR ($CDCl_3$) 1.85 (s, 6 H), 2.29 (s, 3 H), 4.28 (s, 4 H), 6.8–7.1 (m, 4 H) ppm; UV (dioxane) 328 nm (ε 4900), 240 (22 000); fluorescence (dioxane) 429 nm (ϕ_F 0.23); mass spectrum, *m/e* 295 (M^+).

9,10-Dioxa-μ-(4-cyanophenyl)imino-*syn*-(methylene,-methyl)bimane (2m) [μ-(4-CNC_6H_4N)-*syn*-(CH_2,CH_3)B]: 13% yield; yellow crystals (DMF); mp 240 °C dec; IR (KBr) 2220, 1750, 1660, 1630, 1600, 1515, 1430, 1250, 1185, 1160 cm^{-1}; ^1H NMR (Me_2SO-d_6) 1.79 (s, 6 H), 4.72 (s, 4 H), 7.15–7.74 (m, 4 H) ppm; UV (CH_3CN) 333 nm (ε 5000, sh), 281 (26 800), 252 (22 000); fluorescence (CH_3CN) 439 nm (ϕ_F 0.80). Anal. Calcd for $C_{17}H_{14}N_4O_2$: C, 66.67; H, 4.58; N, 18.30. Found: C, 66.51; H, 4.68; N, 18.22.

9,10-Dioxa-μ-(4-bromophenyl)imino-*syn*-(methylene,-methyl)bimane (2n) [μ-(4-BrC_6H_4N)-*syn*-(CH_2,CH_3)B]: 24% yield; yellow crystals (CH_3CN–DMF (2:1)); mp ca. 230 °C dec; IR (KBr) 1755, 1665, 1640, 1495, 1450, 1385, 1240, 1180 cm^{-1}; ^1H NMR (Me_2SO-d_6) 1.84 (s, 6 H), 4.53 (s, 4 H), 6.9–7.4 (m, 4 H) ppm; UV (CH_3CN) 330 nm (ε 5100), 252 (22 500), 231 (20 300); fluorescence (dioxane) 429 nm (ϕ_F 0.68); mass spectrum, *m/e* 359, 361 (M^+).

9,10-Dioxa-μ-(4-chlorophenyl)imino-*syn*-(methylene,-methyl)bimane (2o) [μ-(4-ClC_6H_4N)-*syn*-(CH_2,CH_3)B]: 57% yield; white needles (CH_3CN); mp 246–248 °C dec; IR (KBr) 1755, 1705, 1670, 1650, 1595, 1420, 1230, 1170, 920 cm^{-1}; ^1H NMR (Me_2SO-d_6) 1.79 (s, 4 H), 4.57 (s, 4 H), 7.22 (dd, 4 H) ppm; UV (dioxane) 320 nm (ε 5400), 250 (25 000), 229 (18 000, sh); fluorescence (dioxane) 429 nm (ϕ_F 0.61); mass spectrum, *m/e* 315, 317 (M^+).

9,10-Dioxa-μ-(4-(carboethoxy)phenyl)imino-*syn*-(methylene,methyl)bimane (2p) [μ-(4-$EtOOCC_6H_4N$)-*syn*-(CH_2,CH_3)B]: 20% yield; yellow crystals (CH_3CN–DMF); mp 251 °C dec; IR (KBr) 2980, 1760, 1710, 1685, 1660, 1635, 1605, 1480, 1430, 1280 cm^{-1}; ^1H NMR (Me_2SO-d_6) 1.30 (t, 3 H), 1.81 (s, 6 H), 4.20 (9, 2 H), 4.77 (s, 4 H), 7.00 (s), 7.18 (s) (2 H), 7.68 (s), 7.84 (s) (2 H) ppm; UV (dioxane) 340 nm (ε 4000), 290 (20 200), 225 (22 600); fluorescence (dioxane) 429 nm (ϕ_F 0.63); mass spectrum, *m/e* 353 (M^+).

9,10-Dioxa-μ-(4-methoxyphenyl)imino-*syn*-(methylene,-methyl)bimane (2h) [μ-(4-$CH_3OC_6H_4N$)-*syn*-(CH_2,CH_3)B]: 50% yield; pink-brown crystals (*i*-PrOH); mp 193 °C dec; IR (KBr) 2960, 2920, 1740, 1695, 1670, 1650, 1630, 1510, 1455, 1400, 1360, 1280, 1245, 1235, 1180, 1160, 1100, 1040, 990, 930, 850, 820, 790, 760, 725, 680 cm^{-1}; ^1H NMR ($CDCl_3$) 1.85 (s, 6 H), 3.78 (s, 3 H), 4.20 (s, 4 H), 6.92 (br s, 4 H) ppm; UV (dioxane) 330 nm (sh), 313 (ε 6100), 239 (24 200); fluorescence (dioxane) 429 nm (ϕ_F 0.013); mass spectrum, *m/e* 311 (M^+).

Three different carbon nucleophiles were reacted with *syn*-($BrCH_2,CH_3$)B. Two of the reactants differ only in that one is a methyl ester and the other an ethyl ester; however, this small difference is important with respect to the reactions which may be carried out with the products, as exemplified by the problems encountered in hydrolyzing the esters. The nucleophiles were generated from (1) diethyl malonate, (2) dimethyl malonate, and (3) malononitrile.

9,10-Dioxa-μ-bis(carboethoxy)methylene-*syn*-(methylene,methyl)bimane (4a). *syn*-($BrCH_2,CH_3$)B (5.0 g, 14.2 mmol) and diethyl malonate (2.30 g, 14.2 mmol) in tetrahydrofuran (100 mL) were added dropwise to a sodium hydride suspension (50%, 1.3 g, 29 mmol) in tetrahydrofuran (100 mL) over 2 h. After another 2 h, the dark reaction mixture was neutralized with HCl (0.1 N), the solvent was removed under reduced pressure, water and CH_2Cl_2 were added, the organic phase was separated and dried (Na_2SO_4), and the solvent was removed. The resulting oil was placed on a silica column and eluted with $CHCl_3$, the solvent was removed, and the residue was crystallized to yield **(4a)**, μ-($(COOEt)_2C$)-*syn*-(CH_2,CH_3)B: 1.10 g (22%); colorless prisms (EtOAc); mp 132 °C; IR (KBr) 2920, 1765, 1750, 1730, 1690, 1665, 1635, 1370, 1295, 1240 cm^{-1}; ^1H NMR ($CDCl_3$) 1.19 (t, 3 H), 1.79 (s, 3 H), 3.19 (s, 2 H), 4.10 (s, 2 H) ppm; UV (dioxane) 330 nm (ε 6100), 229 (16 500); fluorescence (dioxane) 426 nm (ϕ_F 0.83); mass spectrum, *m/e* 348 (M^+). Anal. Calcd for $C_{17}H_{20}N_2O_6$: C, 58.62; H, 5.75; N, 8.05. Found: C, 58.97; H, 5.73; N, 8.29.

9,10-Dioxa-μ-bis(carbomethoxy)methylene-*syn*-(methylene,methyl)bimane (4b). Reaction of *syn*-($BrCH_2,CH_3$)B (2.80 g, 8 mmol) and dimethyl malonate (1.06 g, 8 mmol) in the fashion just described for diethyl malonate yielded 0.67 g (26%) of μ-($(COOMe)_2C$)-*syn*-(CH_2,CH_3)B **(4b)**: yellowish crystals (*i*-PrOH); IR (KBr) 2920, 1765 (sh), 1740, 1685, 1660, 1630, 1440, 1375, 1255, 1155 cm^{-1}; ^1H NMR ($CDCl_3$) 1.81 (s, 3 H), 3.22 (s, 2 H), 3.70 (s, 3 H) ppm; UV (dioxane) 329 nm (ε 6100)8 229 (15 100); mass spectrum, *m/e* 320 (M^+).

9,10-Dioxa-μ-dicyanomethylene-*syn*-(methylene,methyl)bimane (4c). *syn*-($BrCH_2,CH_3$)B (2.80 g, 8 mmol) and malonitrile (530 mg, 8 mmol) were reacted according to the procedure for the reaction of the bromide and diethyl malonate, yielding **(4c)**, μ-($(CN)_2C$)-*syn*-(CH_2,CH_3)B: 650 mg (32%); white crystals (CH_3CN); mp 267 °C dec; IR (KBr) 2930, 2250 (weak), 1755, 1740, 1665, 1640, 1445, 1385, 1245, 1040 cm^{-1}; ^1H NMR (Me_2SO-d_6) 1.80 (s, 3 H), 3.96 (s, 2 H) ppm; UV (dioxane) 331 nm (ε 6500), 230 (14 500); fluorescence (dioxane) 426 nm (ϕ_F 0.73); mass spectrum, *m/e* 254 (M^+). Anal. Calcd for $C_{13}H_{10}N_4O_2$: C, 61.42; H, 3.94; N, 22.05. Found: C, 61.67; H, 4.17; N, 22.13.

9,10-Dioxa-μ-thia-*syn*-(methylene,methyl)bimane (5). Two different procedures were used to prepare thia-bridged bimane, the first involving addition of the dibromide in CH_3CN to Na_2S in pH 6.5 aqueous phosphate buffer, the second utilizing two phases and a phase-transfer agent. The second gave a higher yield of product. *syn*-($BrCH_2,CH_3$)B (350 mg, 1 mmol) in benzene (50 mL) and $Na_2S{\cdot}9H_2O$ (325 mg, 2 mmol) and hexadecyltrimethylammonium bromide (50 mg) in water (15 mL) were stirred vigorously for 3 h at 25 °C. The organic phase was separated, the aqueous phase was extracted many times with CH_2Cl_2, the combined organic phases were dried (Na_2SO_4), the solvent was removed, and the solid was crystallized to yield μ-(S)-*syn*-(CH_2,CH_3)B: 135 mg (60%); yellowish crystals (CH_3CN); mp ca. 230 °C dec; IR (KBr) 2980, 1755, 1690, 1630, 1380, 1290, 1150, 1065 cm^{-1}; ^1H NMR (Me_2SO-d_6) 1.90 (s, 3 H), 4.20 (s, 2 H) ppm; UV (CH_3CN) 345 nm (ε 5000), 231 (16 700); fluorescence (CH_3CN) 447 nm (ϕ_F 0.79); mass spectrum, *m/e* 222 (M^+). Anal. Calcd for $C_{10}H_{10}N_2O_2S$: C, 54.04; H, 4.53; N, 12.60. Found: C, 53.78; H, 4.56; N, 12.40.

Reactions of Bridged Compounds. A small number of simple reactions were carried out with each type of bridged derivative: (1) acetylation and alkylation of nitrogen-bridged compounds; (2) acylation and acetonide formation from polyhydroxyalkyl derivatives of nitrogen-bridged compounds; (3) hydrolysis of the esters derived from carbon-bridged compounds; (4) oxidation and alkylation of sulfur-bridged compounds.

9,10-Dioxa-μ-acetylimino-*syn*-(methylene,methyl)bimane (2q). A suspension of μ-(NH)-*syn*-(CH_2,CH_3)B in acetic anhydride (2–2.5 mL/mmol) was refluxed for 2 h, the solvent removed under vacuum, and the residue recrystallized to yield 93% μ-(CH_3CON)-*syn*-(CH_2,CH_3)B **(2q)**: yellowish needles (EtOAc–CH_3CN); mp 210 °C dec; IR (KBr) 2980, 1780, 1765, 1710, 1670, 1645, 1415, 1240, 1150 cm^{-1}; ^1H NMR ($CDCl_3$) 1.87 (s, 6 H), 2.22 (s, 3 H), 4.73 (s, 4 H) ppm; UV (dioxane) 328 nm (ε 5800), 228 (16 700); fluorescence (dioxane) 425 nm (ϕ_F 0.79); mass spectrum, *m/e* 247 (M^+).

9,10-Dioxa-μ-dimethylimmonio-*syn*-(methylene,methyl)-bimane Perchlorate (3a). Reaction of μ-(CH_3N)-*syn*-(CH_2,CH_3)B **(2a)** with CH_3I in acetonitrile yielded a quaternary iodide, μ-$(CH_3)_2N^+$-*syn*-(CH_2,CH_3)BI^-, identical in spectroscopic

properties with the perchlorate derived via the bromide formed by the reaction of *syn*-($BrCH_2,CH_3$)B with dimethylamine. A mixture of *N,N*-diisopropylethylamine (190 mg, 1.43 mmol) and dimethylamine (3.9 M) in dioxane (20 mL) was added to the dibromobimane, *syn*-($BrCH_2,CH_3$)B (500 mg, 1.43 mmol), in dioxane (25 mL). The mixture was stirred for 1 h, and the precipitate filtered off in a glovebag (very hygroscopic!) and dried under high vacuum. The bromide salt was reacted with $AgClO_4$ (0.4 g, 1.9 mmol) in hot CH_3OH, the AgBr filtered while hot, the filtrate concentrated, and the salt filtered off and recrystallized from CH_3OH–H_2O to give 200 mg (43%) of μ-$(CH_3)_2N^+$-*syn*-(CH_2,CH_3)B ClO_4^- (**3a**): yellowish-white crystals; mp 265 °C dec; IR (KBr) 3020, 3010, 2960, 2920, 1760, 1710, 1690, 1650, 1480, 1390, 1230, 1160, 1100, 1020, 990, 940, 900, 800, 760, 730, 700 cm^{-1}; ^1H NMR (D_2O) 1.85 (s, 6 H), 3.25 (s, 6 H), 4.90 (s, 4 H) ppm; UV (D_2O) 340 nm (ϵ 5400), 232 (15 100); fluorescence (D_2O) 466 nm (ϕ_F 0.62).

9,10-Dioxa-μ-*N*-arylimmonio-*syn*-(methylene,methyl)bimane Bromide [Aryl = 4-ClC_6H_4 (3b), 4-$CH_3C_6H_4$ (3c)]. *syn*-($BrCH_2,CH_3$)B (1; 700 mg, 2 mmol) was dissolved in CH_3CN (15 mL) *N,N*-Diisopropylethylamine (1 mL) and *N*-methyl-4-chloroaniline (1 mL, ca. 7.3 mmol) or *N*-methyl-4-methylaniline (1 mL, ca 8.3 mol) were added, and the reaction mixture was stirred for 7 days at room temperature. The precipitated salt was filtered off and recrystallized from *i*-PrOH–H_2O.

μ-(CH_3)(4-ClC_6H_4)N^+-*syn*-(CH_2,CH_3)B Br^- (3b): yellow-white crystals (25% yield); mp 245 °C; IR (KBr) 3580, 3400, 3010, 2930, 2910, 2850, 1750, 1690, 1660, 1640, 1590, 1490, 1400, 1330, 1250, 1210, 1150, 1110, 1040, 1010, 990, 910, 880, 860, 830, 780, 750, 730, 700 cm^{-1}; ^1H NMR (D_2O) 1.80 (s, 6 H), 3.55 (s, 3 H), 5.70 (s, 4 H), 7.8–8.2 (8 H) ppm; UV (H_2O) 340 nm (ϵ 5000), 232 (16 500); fluorescence (H_2O) 465 (ϕ_F 0.40).

μ-(CH_3)(4-$CH_3C_6H_4$)N^+-*syn*-(CH_2,CH_3)B Br^- (3c): yellow-white crystals (20% yield); mp 230 °C; IR (KBr) 3570, 3380, 3000, 2920, 2850, 1750, 1690, 1660, 1640, 1510, 1460, 1390, 1310, 1250, 1200, 1160, 1110, 1040, 1010, 990, 910, 880, 840, 810, 780, 760, 730, 700 cm^{-1}; ^1H NMR (D_2O) 1.80 (s, 6 H), 2.25 (s, 3 H), 3.45 (s, 3 H), 5.50 (s, 4 H), 7.3–7.85 (4 H); UV (H_2O) 340 nm (ϵ 5000), 232 (16 000); fluorescence (H_2O 465 nm (ϕ_F 0.52).

Triol Esters (2fp$_3$, 2fp$_2$, 2fp, fl$_3$, 2fl$_2$, 2fl, 2fa$_3$, 2fa$_2$, 2fa). The trihydroxy-bridged compound μ-($(HOCH_2)_3CN$)-*syn*-(CH_2,CH_3)B (**2f**) (1.0 g, 3.2 mmol) in pyridine (20 mL) was mixed with palmitoyl chloride (1.8 g, 6.5 mmol). After 2 h, the mixture was poured into cold, concentrated HCl (40 mL), and the precipitate was filtered off, washed with 1 N HCl and H_2O, and dried to yield 2.3 g of a mixture of three esters, the mono-, di-, and tripalmitates (three fluorescent spots on TLC). The esters were separated by chromatography on silica gel, yielding the triester **2fp$_3$**, 1000 mg (30.5% yield; eluant benzene–EtOAc, 4:1), the diester **2fp$_2$**, 125 mg (5.0% yield; eluant benzene–EtOAc, 1:1), and the monoester **2fp**, 411 mg (26.0% yield; eluant EtOAc–MeOH, 3:1), total ester yield 61.5%.

9,10-Dioxa-μ-[tris[(palmitoyloxy)methyl]methyl]imino-*syn*-(methylene,methyl)bimane (2fp$_3$) [μ-(($C_{15}H_{31}COOCH_2)_3CN$)-*syn*-(CH_2,CH_3)B]: pale yellow crystals (benzene–petroleum ether (1:5)); mp 62 °C; IR (KBr) 2920, 2840, 1740, 1690, 1470, 1430, 1410, 1290, 1270, 1240, 1220, 1190 cm^{-1}; ^1H NMR ($CDCl_3$) 0.9–1.3 (87 H), 1.9 (s, 6 H), 2.3 (m, 6 H), 3.7 (s, 4 H), 4.2 (s, 6 H) ppm; UV (CH_3CN) 335 nm (ϵ 4000), 227 (6600).

9,10-Dioxa-μ-[bis[(palmitoyloxy)methyl](hydroxymethyl)methyl]imino-*syn*-(methylene,methyl)bimane (2fp$_2$) [μ-(($C_{15}H_{31}COOCH_2)_2(HOCH_2)CN$)-*syn*-($CH_2,CH_3$)B]: yellow crystals (benzene–petroleum ether (1:1); mp 71 °C; IR (KBr) 3470, 2920, 2840, 1740, 1620, 1470, 1410, 1360, 1285, 1270, 1220, 1160 cm^{-1}; 1H NMR ($CDCl_3$) 0.9–1.3 (60 H), 1.9 (s, 6 H), 2.3 (m, 4 H), 3.6 (s, 1 H), 3.7 (s, 4 H), 4.2 (s, 4 H) ppm; UV (CH_3CN) 333 nm (ϵ 4270), 228 (14 550). Anal. Calcd for $C_{46}H_{79}N_3O_7$: C, 70.34; H, 10.06; N, 5.35. Found: C, 70.26; H, 10.22; N, 5.19.

9,10-Dioxa-μ-[(palmitoyloxy)bis(hydroxymethyl)methyl]imino-*syn*-(methylene,methyl)bimane (2fp) [μ-(($C_{15}H_{31}COOCH_2)(HOCH_2)_2CN$)-*syn*-($CH_2,CH_3$)B]: yellow crystals (*i*-PrOH); mp 137 °C; IR (KBr) 3440, 2920, 2840, 1740, 1620, 1470, 1410, 1385, 1360, 1220, 1160, 980 cm^{-1}; ^1H NMR ($CDCl_3$) 0.9–1.3 (29 H), 1.9 (s, 6 H), 2.3 (m, 2 H), 3.7 (s, 4 H), 3.9 (s, 4 H), 4.1 (s, 2 H) ppm; UV (CH_3CN) 333 nm (ϵ 4660), 228 (16 700). Anal. Calcd for $C_{30}H_{49}N_3O_6$: C, 65.83; H, 8.95; N, 7.61. Found: C, 65.65; H, 8.74; N, 7.40.

Acylation of the trihydroxy compound with lauroyl chloride as described above led to a mixture of the mono-, di-, and trilaurate esters, which were separated in a manner similar to that used for the palmitate esters. The trilaurate **2fl$_3$** (36.5% yield) formed pale yellow crystals from petroleum ether, mp 57 °C. The dilaurate **2fl$_2$** (7.2% yield) was obtained as yellow crystals from *i*-PrOH, mp 60 °C. Anal. Calcd for $C_{38}H_{63}N_3O_7$: C, 67.72; H, 9.35; N, 6.24. Found: C, 67.39; H, 8.68; N, 6.27. The monolaurate **2fl** (25.0% yield) gave yellow crystals from *i*-PrOH, mp 100 °C. Anal. Calcd for $C_{26}H_{41}N_3O_6$: C, 63.56; H, 8.35; N, 8.55. Found: C, 63.31; H, 8.79; N, 8.49. Total ester yield was 68.7%. UV (CH_3CN): triester, 330 nm (ϵ 4000), 228 (11 000); diester, 333 (5000), 228 (16 100).

The acetate esters were prepared from the trihydroxy compound in two ways: (1) by reaction with excess acetic anhydride in a small amount of pyridine (heterogeneous reaction, triacetate) or (2) as a solution with the stoichiometric amount of acetic anhydride in a large volume of pyridine (diacetate, monoacetate). The products were purified by chromatography on silica gel, followed by crystallization from *i*-PrOH (triacetate, diacetate) or CH_3CN (monoacetate).

Triacetate 2fa$_3$ [μ-(($CH_3COOCH_2)_3CN$)-*syn*-(CH_2,CH_3)B]: white crystals; mp 105 °C; IR (KBr) 2940, 2840, 1780, 1750, 1735, 1680, 1650, 1390, 1240, 1150, 1090, 1050, 900, 770, 610 cm^{-1}; ^1H NMR ($CDCl_3$) 1.836 (s, 6 H), 2.100 (s, 9 H), 3.899 (s, 4 H), 4.287 (s, 6 H) ppm; UV (CH_3CN) 333 nm (ϵ 6080), 228 (20 500).

Diacetate 2fa$_2$ [μ-(($CH_3COOCH_2)_2(HOCH_2)CN$)-*syn*-(CH_2,CH_3)B]: white crystals; mp 148–149 °C; IR (KBr) 3500, 2960, 2940, 1760, 1740, 1660, 1640, 1390, 1260, 1170, 1050, 760 cm^{-1}; ^1H NMR ($CDCl_3$) 1.813 (s, 6 H), 2.106 (s, 6 H), 3.776 (s, 2 H), 3.984 (s, 4 H), 4.30 (s, 4 H) ppm; UV (CH_3CN) 333 nm (ϵ 5700), 230 (25 300).

Monoacetate 2fa [μ-(($CH_3COOCH_2)(HOCH_2)_2CN$)-*syn*-(CH_2,CH_3)B]: pale yellow crystals; mp 165 °C; IR (KBr) 3450, 2940, 1770, 1750, 1630, 1390, 1230, 1170, 1020, 750 cm^{-1}; ^1H NMR ($CDCl_3$) 1.823 (s, 6 H), 2.123 (s, 3 H), 3.792 (s, 4 H), 4.017 (s, 4 H), 4.235 (s, 2 H); UV (CH_3CN) 333 nm (ϵ 5500), 228 (20 300).

9,10-Dioxa-μ-[[acetonidobis(hydroxymethyl)](hydroxymethyl)methyl]imino-*syn*-(methylene,methyl)bimane (2fA). A mixture of the trihydroxy compound, μ-($(HOCH_2)_3CN$)-*syn*-(CH_2,CH_3)B (**2f**; 1.0 g, 2.3 mmol), dry acetone (40 mL), *p*-toluenesulfonic acid (1 mg), and anhydrous magnesium sulfate (3.0 g) were refluxed for 7 h, the mixture was cooled, $NaHCO_3$ was added, the solution was filtered, the solvent was evaporated, and the residue was chromatographed on silica gel (eluant EtOAc–CH_3CN, 1:1) to yield the acetonide μ-(($CH_2OC(CH_3)_2OCH_2$)($HOCH_2$)CN)-*syn*-(CH_2,CH_3)B (**2fA**): 350 mg (40%); pale yellow crystals (CH_3CN); mp 265 °C (the crystals are especially attractive and resemble marquise-cut diamonds); IR (KBr) 3480, 3000, 2940, 2900, 2820, 1750, 1690, 1660, 1625, 1490, 1460, 1420, 1390, 1330, 1270, 1210, 1170, 1110, 1080, 1055, 1030, 990 cm^{-1}; NMR (Me_2SO-d_6) 1.35 (s, 6 H), 1.80 (s, 6 H), 3.55 (s, 4 H), 3.65 (s, 2 H), 3.90 (s, 4 H) ppm; UV (CH_3CN) 333 nm (ϵ 4850), 230 (15 700); mass spectrum, *m/e* 349 (M^+). Anal. Calcd for $C_{17}H_{23}N_3O_5$: C, 58.48; H, 6.58; N, 12.03. Found: C, 58.62; H, 6.66; N, 11.94.

9,10-Dioxa-μ-carboxymethylene-*syn*-(methylene,methyl)bimane (4f). A suspension of dimethyl ester **4b** (μ-$(COOMe)_2$C-*syn*-(CH_2,CH_3)B; 400 mg, 1.25 mmol) in 15% HCl (5 mL) was heated at 80 °C until all of the solid had dissolved (ca. 30 min). After the mixture cooled, the precipitated solid was filtered off and recrystallized to yield μ-(HOOCCH)-*syn*-(CH_2,CH_3)B (**4f**): 120 mg (39%); yellowish crystals (*i*-PrOH); mp 248–250 °C; IR (KBr) 3270 (br), 1740, 1660, 1620, 1440 (sh), 1385, 1240, 1180, 1160 cm^{-1}; ^1H NMR (Me_2SO-d_6) 1.72 (s, 6 H), 3.30 (m, 4 H), 3.71 (s, 1 H) ppm; UV (dioxane) 335 nm (ϵ 6000), 230 (18 000); fluorescence (dioxane) 427 nm (ϕ_F 0.82); mass spectrum, *m/e* 240 (M^+).

9,10-Dioxa-μ-(carbomethoxy)methylene-*syn*-(methylene,methyl)bimane (4d). Dimethyl ester **4b** (0.80 g, 2.50 mmol) and lithium iodide dihydrate (1.30 g, 7.5 mmol) in DMF were refluxed for 15 h, the solvent was removed under vacuum, and the residue was transferred to a silica column and chromatographed to yield μ-(MeOOCCH)-*syn*-(CH_2,CH_3)B (**4d**): 0.25 g (33%); yellowish crystals (*i*-PrOH–Et_2O); mp 194 °C; IR (KBr)

2970, 2940, 1750, 1720, 1650, 1620, 1440, 1400, 1285, 1250, 1220, 1160 cm^{-1}; ^{1}H NMR ($CDCl_3$) 1.86 (s), 1.87 (s) (6 H), 3.09 (s), 3.12 (s), 3.29 (m) (5 H), 3.90 (s, 3 H) ppm; UV (dioxane) 333 nm (ϵ 5500), 230 (13 300); fluorescence (dioxane) 427 nm (ϕ_F 0.65); mass spectrum, m/e 262 (M^+).

9,10-Dioxa-μ-dicarboxymethylene-*syn*-(methylene,methyl)bimane (4e). Dimethyl ester **4b** (280 mg, 0.88 mmol) in trimethylsilyl iodide (800 mg, 4 mmol) was heated under N_2 at 100 °C for 15 h, the dark red mixture mixed with water (5 mL) and ether (15 mL), the suspension stirred for 15 min, and the solid filtered off and recrystallized to yield μ-((HOOC)$_2$C)-*syn*-(CH_2,CH_3)B (**4e**): 175 mg (68%); bluish-white crystals (*i*-PrOH); mp 255 °C; IR (KBr) 3480, 3200, 1715 (br), 1640, 1385, 1305, 1250, 1200, 1175, 1120, 1080, 790, 760 cm^{-1}; ^{1}H NMR (Me_2SO-d_6) 1.70 (s, 6 H), 3.21 (s, 4 H) ppm; mass spectrum (CI), m/e 249 [(M+1)$^+$ − CO_2].

9,10-Dioxa-μ-methylthianio-*syn*-(methylene,methyl)bimane Fluorosulfate (5a). μ-(S)-*syn*-(CH_2,CH_3)B (**5**; 250 mg, 1.13 mmol) and methyl fluorosulfate (0.5 mL) were stirred together for 15 h, and CH_2Cl_2 (10 mL) and MeOH (10 mL) were then added. After the solid had dissolved, the solvent was removed and the residue recrystallized to yield μ-(CH_3S^+)-*syn*-(CH_2,CH_3)B FSO_3^- (**5a**): 210 mg (56%); yellow powder (EtOAc + 5% CH_3CN); mp 210 °C dec; IR (KBr) 1760, 1680, 1630, 1385, 1180, 1160, 1070, 1020 cm^{-1}; ^{1}H NMR (Me_2SO-d_6) 1.81 (s, 6 H), 2.89 (s, 3 H), 5.0 (m, 4 H) ppm; UV (CH_3CN) 356 nm (ϵ 6000), 256 (13 700), 232 (21 600); fluorescence (CH_3CN) 440 nm (ϕ_F 0.37).

9,10-Dioxa-μ-sulfono-*syn*-(methylene,methyl)bimane (5b). μ-(S)-*syn*-(CH_2,CH_3)B (**5**; 224 mg, 1 mmol) and *m*-chloroperbenzoic acid (515 mg, 3 mmol) in CH_2Cl_2 (30 mL) were stirred for 3 h at 25 °C, during which the initial suspension changed character. The solid was filtered off, washed, and recrystallized to yield μ-(SO_2)-*syn*-(CH_2,CH_3)B (**5b**): 190 mg (75%); colorless crystals (CH_3CN); mp >300 °C (blackens >270 °C); IR (KBr) 2980, 2920, 1775 (sh), 1760, 1700, 1660, 1645, 1410, 1370, 1345, 1270, 1195, 1170, 1150, 1090, 1075, 775, 760 cm^{-1}; ^{1}H NMR (Me_2SO-d_6) 1.80 (s, 3 H), 4.95 (s, 2 H) ppm; UV (CH_3CN) 333 nm (ϵ 5750), 236 (17 500); fluorescence (CH_3CN) 441 nm (ϕ_F 0.88); mass spectrum, m/e 254 (M^+).

Acknowledgment. We are grateful to Gilda Iny, Dov Faust, and Yonah (Cohen) Faust for various types of help during the course of the work, for partial support from a grant from the Israel Academy of Sciences, and to Professor R. Neidlein, Pharmazeutisch-Chemisches Institut, Universität Heidelberg, for help with the elemental analyses.

Registry No. 1, 68654-25-1; **2a**, 76421-31-3; **2b**, 76421-32-4; **2c**, 76421-33-5; **2d**, 76421-34-6; **2e**, 76421-35-7; **2f**, 76421-36-8; **2fa**, 76421-37-9; **2fa$_2$**, 76421-38-0; **2fa$_3$**, 76421-39-1; **2fA**, 76421-40-4; **2fl**, 76421-41-5; **2fl$_2$**, 76421-42-6; **2fl$_3$**, 76421-43-7; **2fp**, 76421-44-8; **2fp$_2$**, 76421-45-9; **2fp$_3$**, 76421-46-0; **2g**, 76421-47-1; **2h**, 76421-48-2; **2i**, 76421-49-3; **2j**, 76421-50-6; **2k**, 76421-51-7; **2l**, 76421-52-8; **2m**, 76421-53-9; **2n**, 76421-54-0; **2o**, 76421-55-1; **2p**, 76421-56-2; **2q**, 76421-57-3; **3a**, 76421-59-5; **3b**, 76421-60-8; **3c**, 76421-61-9; **4a**, 76421-62-0; **4b**, 76421-63-1; **4c**, 70090-46-9; **4d**, 76421-64-2; **4e**, 76421-65-3; **4f**, 76421-66-4; **5**, 74317-61-6; **5a**, 76421-68-6; **5b**, 74317-60-5; ammonium hydroxide, 1336-21-6; methylamine, 74-89-5; ethylamine, 75-04-7; *tert*-butylamine, 75-64-9; 2-aminoethanol, 141-43-5; tris(hydroxymethyl)aminomethane, 77-86-1; hydroxylamine hydrochloride, 5470-11-1; benzylamine, 100-46-9; 4-methoxybenzylamine, 2393-23-9; aniline, 62-53-3; 4-methylaniline, 106-49-0; 4-cyanoaniline, 873-74-5; 4-bromoaniline, 106-40-1; 4-chloroaniline, 106-47-8; 4-(carbethoxy)aniline, 94-09-7; 4-methoxyaniline, 104-94-9; diethyl malonate, 105-53-3; dimethyl malonate, 108-59-8; malononitrile, 109-77-3; acetic anhydride, 108-24-7; *N*-methyl-4-chloroaniline, 932-96-7; *N*,4-dimethylaniline, 623-08-5; palmitoyl chloride, 112-67-4; lauroyl chloride, 112-16-3; Na_2S, 1313-82-2.

Kinetics and Mechanism of the Reaction of 10-Phenylphenothiazine Dication with Water in Acetonitrile

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Received September 22, 1980

The reaction of electrogenerated 10-phenylphenothiazine (PPTZ) dication (PPTZ^{2+}) with water was investigated in acetonitrile containing 0.5 M $NaClO_4$ by cyclic voltammetry and controlled-potential electrolysis. The cyclic voltammogram of PPTZ showed two reversible redox waves at water concentrations of less than 3 mM at a scan rate of 0.2 V s^{-1}. When the water concentration was increased, the return peak for the second wave, which is due to reduction of the dication to the cation radical, disappeared, while the cation radical was still stable (up to at least 260 mM H_2O) during the time scale of the voltammetric measurements. By controlled-potential electrolysis (CPE) at 1.0 V vs. Ag/Ag$^+$ for 1–5 mM PPTZ solutions containing 20–260 mM water, anodically generated PPTZ^{2+} was found to react with water to give 5-hydroxy-10-phenylphenothiazinium ion (PPTZ(OH)$^+$) which was further deprotonated by addition of an excess of water to the solution to form 10-phenylphenothiazine 5-oxide (PPTZ(O)). The kinetic study using a cyclic voltammetric technique indicated that the rate law was given as $-d[PPTZ^{2+}]/dt = k_f[PPTZ^{2+}][H_2O]^2$ at various temperatures tested (−20 to +30 °C), where k_f = 2.4 ± 0.5 × 10^4 M^{-2} s^{-1} at 25 °C. From the kinetic data obtained, the activation enthalpy and activation entropy were estimated to be $\Delta H^\ddagger$ = 30.5 kJ/mol (7.3 kcal/mol) and $\Delta S^\ddagger$ = −58.5 J/(mol K) (−14 eu), respectively. The rate law and the activation parameters are explained in terms of the following reactions: $PPTZ^{2+} + H_2O \rightleftharpoons PPTZ(OH_2)^{2+}$, $PPTZ(OH_2)^{2+} + H_2O \rightarrow PPTZ(OH)^+ + H_3O^+$ (rds), and $PPTZ(OH)^+ + H_2O \rightleftharpoons PPTZ(O) + H_3O^+$, where the activation step is the nucleophilic attack by water to form a $PPTZ(OH_2)^{2+}$–H_2O adduct following fast deprotonation to give PPTZ(OH)$^+$. The stepwise process proposed for the nucleophilic attack by water on PPTZ^{2+} seems to be a rather usual reaction pathway in nucleophilic addition to dications.

The nucleophilic addition to anodically generated electrophiles such as cation radicals has been a subject of much attention in recent electroorganic studies.[1] Reactions of cation radicals of 9,10-diphenylanthracene[2-4] and

0022-3263/81/1946-1679$01.25/0